An integrated methodology for treatment and valorisation of agricultural wastes in Lesvos, Greece

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Abstract
A pilot agrowaste treatment facility is installed in the Waste Management Laboratory of the University of the Aegean (Greece). The main target of the project is to apply methods (anaerobic digestion, composting, combustion and pyrolysis) for the treatment and valorisation of agro-waste taking into account the specific characteristics of each type of feedstock. All the parameters affecting the digestion process will be monitored to maximize the biogas production and optimize the method. Mixing different wastes, will provide a solution to the seasonal variations or the small quantity of waste produced in some cases in Lesvos island. Preliminary experiments have been conducted using food residues mixed with olive mill waste (OMW) in order to evaluate the composting procedure and the final product (compost). Determination of the physico-chemical parameters were carried out. and the phytotoxicity of the final product was assessed. Results showed that all the composting factors followed the general pattern of a composting procedure except some “abnormalities” due to the OMW presence. Composts were evaluated as mature but phytotoxic.

1. Introduction

The agri-food sector has been a key pillar of economic growth in the islands of the North Aegean Region for centuries. Olive oil, cheese, wine, citrus, milk, mastic, ouzo as well as other products are a result of the combination of the special geoclimatic conditions of the North Aegean region and the traditional production practices.

However, significant amounts of by-products and residues - bio-waste are produced during production and processing. Waste management of olive oil mills, dairies and wineries, slaughterhouse waste, livestock waste and residues during fruit processing is a major environmental and economic problem for the enterprises. The seasonal variation and the specific characteristics of these by-products makes it even more difficult to find a viable solution for their rational and effective management. A typical example is the problem of olive mill wastewater management. High organic load makes its treatment with the traditional methods very difficult, thus increasing the risk from its disposal to the natural environment. On the other hand, agro-waste can be considered as energy and raw materials source (Demirbas *et al.*, 2011). Thermal methods (combustion, pyrolysis) and biological processes (anaerobic digestion) can be used for their exploitation leading to the production of energy and the formulation of new products. (Pyo *et al.*, 2014; Ragazzi and Rada, 2013). The selection of the method usually depends on the water content of the feedstock.

Food waste is a significant issue that encompass social, nutritional and environmental concerns (Cicatiello *et al.*, 2017). They are produced in every stage of the food value chain and in different types thus they have attracted the worldwide attention (Zhao, 2019). An approximately estimation of the food losses and wastes throughout the food chain around the globe is one third of the produced food for human consumption, namely, 1.3 billion tons per year (FAO, 2011). Composting this huge quantity of food waste can provide a balance of nutrients through compost that can be applied in agriculture (Cerda *et al.*, 2017).

In Mediterranean countries, where the majority of the global olive oil is produced, the olive mill wastes are produced in huge quantities. The global production of OMW is estimated to be 10 to 30 m^3(Souilem *et al.*, 2017). Moreover, their malodorous emissions, acidic pH and high chemical oxygen demand (COD) show them off as a significant environmental problem (Ntougias *et al.*, 2013). However, OMW are rich in important nutrients for the plants and organic matter, which make them a potential ideal material for composting in order to be bio-converted in fertilizer and soil conditioner (Dermeche *et al.*, 2013).

Composting is a biochemical process producing a final product known as compost through the biological decomposition of the organic matter. Through this procedure mineral nutrients (N, P, K) which are present in organic wastes are recycled and could be used for agriculture applications (Onwosi *et al.*, 2017). It is an alternative method for organic wastes treatment that can reduce the wastes which end up to landfills, prevent the contamination of the ground water, reduce greenhouse gas (GHG) emissions and produce a product that can be useful as an organic fertilizer or soil amendment (Li *et al.*, 2013).

High quality compost which is proper for agricultural use is a compost that is stable and mature. These two terms are encountered widely in literature and there is an alternation between them. Stability refers to the degree that organic matter has been decomposed and so to the degree of microbial activity, and maturity is related with the phytotoxicity of compost (Epstein, 1997, Cerda *et al.*, 2017, Komilis & Tziouvaras, 2009).

The aim of this work was to assess the composting procedure of food wastes mixed with olive oil mill waste. The results will serve as preliminary experiments (lab scale) of a research infrastructure that has just been installed and will be used for the treatment and valorisation of various agricultural wastes and residues in North Aegean Region (Greece). The main target of the project is to further develop and validate a novel methodology dedicated to fully exploit the organic carbon and nutrient content of agro-waste in the concept of circular economy. A schematic representation of the proposed unit is shown in Figure 1.

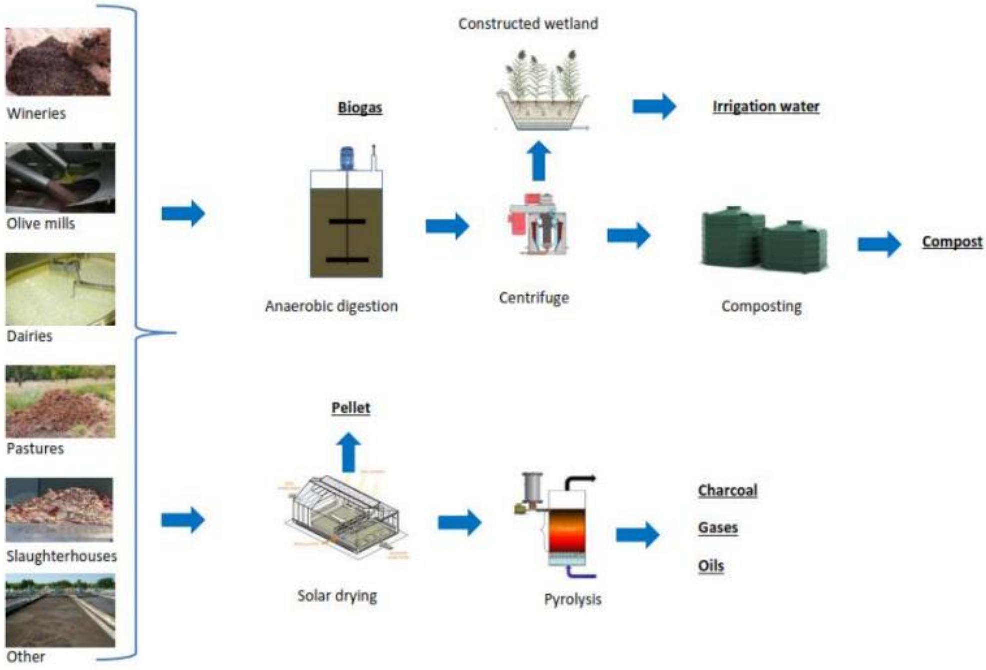


Figure 1. The proposed infrastructure for the treatment of agricultural wastes and residues in Lesvos, Greece.

Composting of food waste and olive mill wastes (three-phase olive mill wastewater (3POMWW) and two-phase olive mill waste (2POMW) was carried out in this work. Olive tree leaves and shavings were used as bulking agents. The possibility to produce high quality compost and simultaneously to define potential difficulties to the composting procedure because of the OMW was investigated.

2. Preliminary experiments

2.1. Composting material, experimental design

Food residues from student's restaurant of University of the Aegean were used as the main substrate for the experiment. They consisted of cooked food, vegetables, fruits and sweets. In addition, two-phase olive mill waste (2POMW) as well as three phase olive mill wastewater (3POMWW), olive tree leaves (OTL) and olive tree shavings (OTS) were used.

Composting period lasted 4-5 months. Three piles, of approximately 250 kg each, were placed outdoors. The first pile (F) was consisted only of food residues and was used as the control pile. In the second one (FOL), 2POMW, 3POMWW and leaves were added. The third one (FOS) was of the same composition as the second one but contained wood shavings instead of leaves. The olive tree leaves and shavings were used as a bulking agent and they were not added from the beginning of the process, to monitor the effect of the olive mill wastes without bulking agent.

2.2. Physico-chemical monitoring and analyses

Oxygen (O_2) and temperature were measured almost every day till the end of the thermophilic phase at the center and the surface of the piles. Afterwards, measurements were sparse. Physico-chemical parameters such as pH, moisture, total Kjeldahl nitrogen and organic carbon were also determined in samples that were taken from different parts of the piles and afterwards homogenized for each pile separately. The aeration of the piles was passive by mixing them with a shovel when there was lack of oxygen and on the other hand to homogenize the composting material. Maintenance of the moisture level (40%–65%) (Agnew & Leonard 2003) was made by adding water whenever was required.

2.3. Stability and maturity

Degradation rate of the organic matter was assessed by measuring the CRI_T (Cumulative Respiration Index for T days) of the microorganisms (Komilis *et al.*, 2011) using a four days respiration test (AT4) according to Austrian Standards for Respiration Activity (Binner *et al.*, 2012; Komilis and Tziouvaras, 2009). Germination tests were carried out with cress seeds (*Lepidum sativum*) in composts extracts to evaluate the phytotoxicity (Himanen and Hänninen, 2011; Tiquia *et al.*, 1996) by using the GI (Germination Index) (Kazamias *et al.*, 2017; Tiquia *et al.*, 1996)

3. Results and discussion

3.1 Procedure's parameters

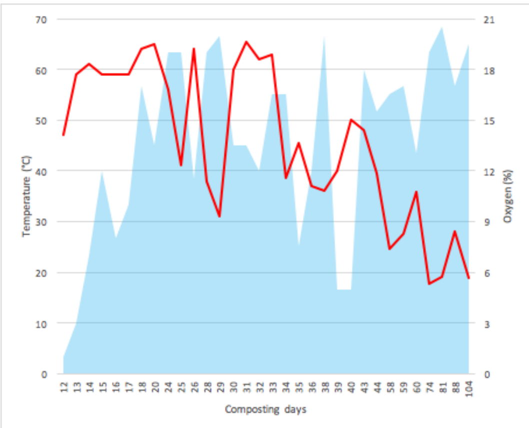
Physico-chemical characteristics of the initial materials are presented in Table 1. It is obvious that the composting substrates at the beginning were acidic which can possible suspend the action of the microorganisms (Awasthi *et al.*, 2017; Sundberg, *et al.*, 2004; Waqas *et al.*, 2017). In fact, there was inhibition of the composting procedure for both FOL and FOS piles probably because of the olive mill wastes addition, which was dealt with the addition of the bulking agents (OTL, OTS). According to the results, the pH values of all piles reached close to 9 during the thermophilic phase and then started to decrease (Figure 3). High values (pH > 8) favor ammonium nitrogen volatilization as ammonia (Azim *et al.*, 2018; Onwosi *et al.*, 2017).

Table 1. Physicochemical characteristics of initial materials

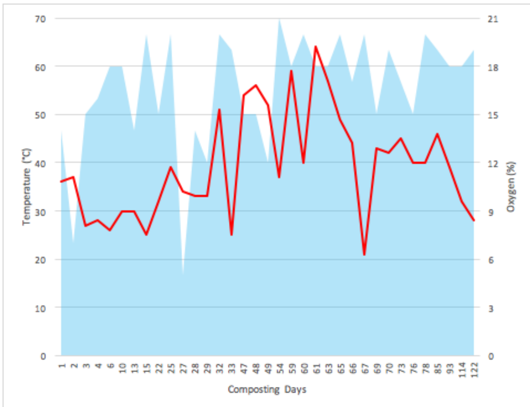
	pH	RW (%)	TOC (%)	TKN (%)	C/N
Food Residues*	3.4-5.5	65-80	33 -54	0.09 - 16.7	2.8 - 24.9
2POMW	4.6	71			
3POMWW	4.6	-		0.3 - 1.2**	
OTL	-	34	43	1.3	33
OTS	-	36	45	0.7	64

**Sources: Chang and Hsu 2008, Cerda et al. 2017, Awasthi et al. 2018, Oviedo-Oca.a et al., 2015, Manu et al., 2017, Adhikari et al. 2008, ** Azbar et al. 2010*

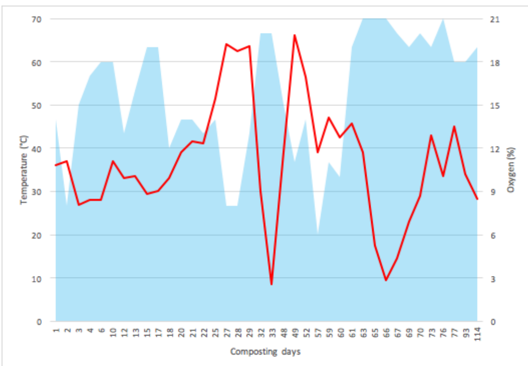
Temperature profile was as usual for pile F, while for piles FOL and FOS the process a lag phase existed, and temperature started to increase to normal levels and follow the standard composting profile only after the addition of leaves and wood. Maximum temperature values were found 65.5, 59.5 and 66 °C for F, FOL and FOS respectively (Figure 2).



(a)



(b)



(c)

Figure 2. Temperature (red line) and oxygen levels (blue area) during composting process of food wastes and mixtures of food with olive-oil mill wastes. (a): F, (b): FOL, (c): FOS)

Oxygen levels in F pile were low from the beginning till the end of the thermophilic phase due to the good performance of the microorganisms and pile's low porosity. For this reason, there was a necessity for almost daily mixing. The other two piles didn't need excess of oxygen supply, except a few times (Figure 2), attributable at first to a nearly inactive phase and then to addition of bulking agents (Rynk, 1992).

C/N ratio was determined a few days after the end of material supply and was found to be 18, 12 and 17 for piles F, FOL and FOS respectively. This shows that C/N ratio was lower than the optimum (25–35), however, it has been shown by recent studies that composting can be effective at a lower C/N ratio as 15 (Azim *et al.*, 2018). A drawback of low C/N numbers is nitrogen losses by ammonia volatilization (Muktadirul Bari Chowdhury *et al.*, 2013). Nevertheless, in this study piles F and FOS had a quite stable nitrogen content through the procedure. The progression of the C/N ratio in our research (Figure 3) was typical for composting (Awasthi *et al.*, 2017; Cerda *et al.*, 2017; El Fels *et al.*, 2014).

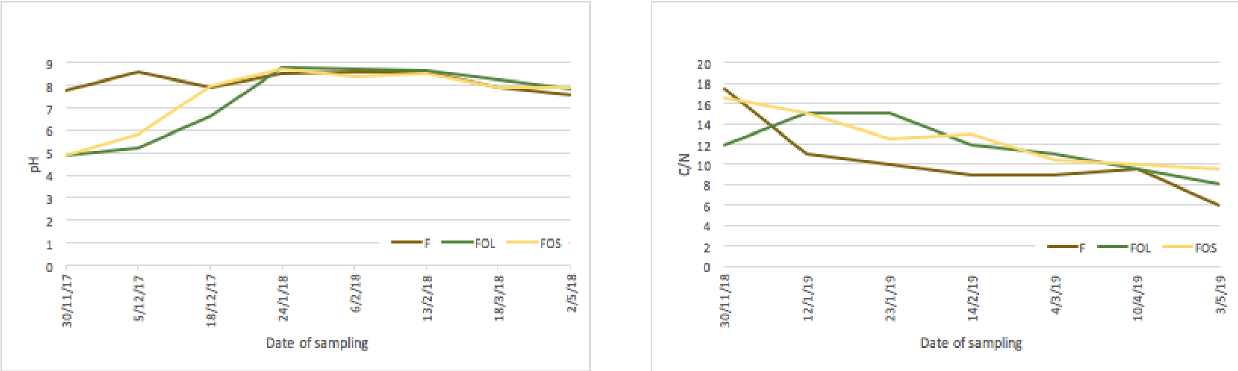


Figure 3. pH values and carbon to nitrogen ratio values (C/N) during composting process of food wastes and mixtures of food with olive-oil mill wastes

3.2 Determination of qualitative parameters in the final product

The pH values of the final product were 7.58, 8.22 και 7.92 for F, FOL and FOS respectively (Figure 3). The typical pH range for a mature compost is 6-8.5 (Komilis and Tziouvaras, 2009; Onwosi *et al.*, 2017; Waqas *et al.*, 2017; WRAP, 2014). C/N ratio values at the end of the process were less than 15 (Figure 3). According to Azim, (2018) a compost with C/N less than 15 can be characterized as stable. CRI values (F=6,2 g O_2/kg dw, FOL=9,9 g O_2/kg dw, FOS=6,7g O_2/kgdw) also indicate stability for the end products. Low values represent a reduction of the available organic matter for degradation, thus less oxygen demand (Godley *et al.*, 2004; Gómez *et al.*, 2005). Komilis and Tziouvaras, (2009) refer that CRI<10 g O_2/kgdw is a characteristic of stable composts. In terms of compost's phytotoxicity none of this study passed the 80% germination limit (Kazamias *et al.*, 2017; Tiquia *et al.*, 1996). An interesting result was observed in FOL, in which despite the high CRI value, compared to other two piles, GI value was better.

4. Conclusion

The addition of olive mill wastes for composting with food residues drops the pH less than five and halt the process in absence of bulking agent. Adding the latter shows an immediate increase in temperature and continuance of the procedure. Low C/N ratio has as a result nitrogen volatilization, subsequently nutrients loss, and bad odors therefore there should be a cautious compilation of the substrate. In the context of phytotoxicity it seems that OMW induced the germination of the seeds therefor it needs more research. The composting materials couldn't achieve the production of a high-quality compost. On the other hand, the findings of the study are not discouraging thus more research is ongoing.

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